Interpretation of Ground Shaking from Paleoliquefaction Features

Grant Award 01-HQ-GR-0030

Dr. Timothy D. Stark
Stark Consultants, Inc.
401 W. Indiana Ave. Urbana, IL 61801
Telephone: (217) 840-8263
Email: stark@shout.net
Additional Investigators: Dr. S. F. Obermeier, E. J. Newman, and J. M Stark

NEHRP Element: II (Memphis Metropolitan Area)
Keywords: Paleoliquefaction, Strong Ground Motion, Earthquake Scenarios
October 14, 2001

Annual Summary

Evidence in the geologic record, e.g. buried liquefaction features, can be used to determine the magnitude of earthquakes that occurred before the advent of seismic recording devices. Marginal liquefaction represents the threshold where the driving forces caused by earthquake shaking are essentially equal to the resisting strength of the soil. If the resisting strength of the soil at a site of marginal liquefaction is known, the driving force and thus the maximum acceleration and magnitude of the earthquake can be back-calculated. The main objectives of this study are to develop a procedure to back-calculate the magnitude and acceleration of an historic earthquake using marginal paleoliquefaction features and to use the procedure with marginal paleoliquefaction features found near Memphis, Tennessee to estimate the magnitude and acceleration of the New Madrid earthquakes of 1811 –1812.

Evidence in the geologic record, e.g. buried liquefaction features, can be used to determine the magnitude of earthquakes that occurred before the advent of seismic recording devices. Marginal liquefaction represents the threshold where the driving forces caused by earthquake shaking are essentially equal to the resisting strength of the soil. If the resisting strength of the soil at a site of marginal liquefaction is known, the driving force and thus the maximum acceleration and magnitude of the earthquake can be back-calculated. Sites of no liquefaction and extensive liquefaction are not as useful in this regard because the back-calculation only provides a lower bound and upper bound, respectively, of the earthquake magnitude and acceleration whereas a marginal liquefaction site provides a direct estimate of the earthquake shaking.

The main objectives of the study are to develop a procedure to back-calculate the magnitude of the New Madrid earthquakes of 1811-1812 using marginal paleoliquefaction features found near Memphis, Tennessee and to use the procedure to estimate the magnitude and acceleration of the 1811 –1812 earthquakes. To accomplish the objectives, a field search headed by Dr. Stephen Obermeier was conducted to locate sites exhibiting features of marginal liquefaction in the vicinity of Memphis. The selected sites are along the Wolf River, in the eastern suburbs of Memphis, between the towns of Germantown and Collierville. The sites contain a number of small dikes extending upward into the overlying clay cap, such as the one shown in Figure 1, and other small features that are deemed to be manifestations of marginal liquefaction.

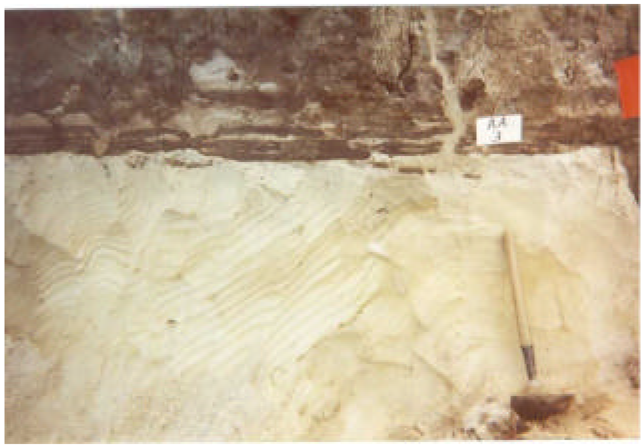

Figure 1 Small sand dike cutting into clay cap is evidence of marginal liquefaction

Field cone penetration testing was conducted at the sites of marginal liquefaction features to obtain information about the current strength of the soil. In particular, data from seven continuous cone penetration tests (CPT) taken near the site were obtained for this study. A portable dynamic cone penetrometer (DCP) was used to obtain readings next to or in the liquefaction features, which are located in the river banks and thus are inaccessible to the truck-mounted CPT rig. In order to correlate the DCP test data to equivalent CPT values, DCP testing was conducted adjacent to two of the CPT test sites. A correlation that converts DCP (blow count) values to equivalent CPT (q_c) penetration resistance was developed during this study that allows the portable and more cost-effective DCP to be used in the Memphis area. The next phase of the research will focus on developing a similar correlation for the New Madrid Seismic Zone (NMSZ) so the DCP can be used to evaluate liquefaction potential and perform back-calculations using paleoliquefaction features in the NMSZ.

Samples of the sand in the liquefaction features and in the source beds for the features were also collected during the DCP tests and were used to conduct grain size analyses. The range of grain size distributions developed for the soil samples falls completely within the boundaries for most liquefiable soils as defined by Ishihara et al. (1989). This supports the field observations and confirms that the chosen test sites represent locations of previous marginal liquefaction.

In order to determine the driving force that would have caused liquefaction at a given site, it is necessary to make a determination of what the resisting strength of the soil was just prior to the earthquake shaking. To relate the current penetration resistance values to values of penetration resistance prior to the earthquake, it is necessary to account for the processes that the soil has been subjected to since the earthquake. These processes include aging of the soil over time, densification due to the liquefaction event, and changes in the water table, e.g. due to drainage and/or flood control measures.

The phenomenon of soil aging results in soils gaining strength over time. This process is well recognized but attempts to quantify this strength gain are preliminary and ongoing. Three previous studies developed expressions to predict the increase in penetration resistance for sands over time. These three expressions were applied for the 189-year time period since the New Madrid earthquakes of 1811-1812 and yielded expected increases in cone penetration resistance, i.e. soil strength, of 176% to 392%. It was determined to use the expression by Mesri et al. (1990) for this study because it yields a moderate increase in penetration resistance to account for aging effects.

The process of liquefaction also leads to densification of the soil and thus increased penetration values. Review and analysis of Standard Penetration Test (SPT) N values measured before and immediately after the occurrence of liquefaction (so little if any aging occurred) for three Japanese earthquakes shows that the N values increased by about 25%. Relating a 25% increase in N values to a corresponding decrease in void ratio through the use of relative density relationships shows an expected decrease in void ratio of 4-10%, depending on the initial value of N and the level of earthquake shaking. To corroborate this 4-10% decrease in void ratio, the results of three studies that measured the change in void ratio due to liquefaction were utilized. Laboratory testing as well as field testing conducted for these studies show a decrease in void ratio of 10-13% after the occurrence of liquefaction. As a result, there is agreement between the field and laboratory testing that shows densification by liquefaction causes a decrease in void ratio of approximately 10%, which corresponds to a 25% decrease in the N value. This decrease in N value has been related to a change in cone penetration resistance by an empirical relationship presented by Stark and Olson (1995) and used as a guide in the back-analysis using the marginal liquefaction features.

Another factor that has a marked influence on liquefaction susceptibility is the depth of the water table. At the Wolf River study area just east of Memphis, the depth of the water table at the time of the 1811 – 1812 earthquakes was determined by field observation to be about 3 m. This portion of the Wolf River has been recently downcut due to a downstream channelization project. This downcutting has exposed the previous depth of oxidation at about 2.5 m below the ground surface and exposed a layer of organic debris about 3 m down that would have decomposed had it ever been above the water table. Another indication of the depth of the water table prior to the 1811 – 1812 earthquakes is the minimum depths of the bases of the liquefaction dikes along the river. The uppermost base of these dikes gives a lower bound to the historic depth of the water table. No dikes were observed to originate in sands less than about 3.5 m below the current ground surface. Accounting for 0.5 m of deposition of sediment in the intervening years, the maximum depth of the water table at the time of the 1811 – 1812 earthquakes is estimated to be about 3 m below the ground surface at the Wolf River test sites. This is shallower than the water table depth of 6 m measured during CPT testing in the summer of 2000.

A methodology known as the Simplified Procedure has been a standard for 30 years for evaluating the liquefaction resistance of soils. The method compares two quantities, the seismic demand on a soil layer, known as seismic stress ratio (SSR), and the capacity of the soil to resist liquefaction, expressed as the seismic resistance ratio (SRR), to determine if liquefaction will occur at a given location. A site of previous marginal liquefaction represents a state where the SSR driving force of the earthquake is approximately equal to the SRR resisting strength of the soil, i.e. the threshold for liquefaction occurrence had just been reached. SSR is a function of the maximum acceleration, a_{max}, and magnitude generated by the earthquake. If the SRR resisting strength of the soil just prior to the earthquake is known at a site of marginal liquefaction, the SSR and thus a_{max} and magnitude generated by the earthquake can be back-calculated.

A spreadsheet was developed that makes use of current penetration resistance values and the Simplified Procedure to back-calculate a_{max} for an historic earthquake. Digital soundings from CPT testing can be imported directly to the spreadsheet. Penetration resistance (q_c) values and corresponding depths can also be entered manually. The user is required to input the depth of the water table at the time of interest and trial values of a_{max} and magnitude. The spreadsheet normalizes the q_c values and corrects for unequal pore water pressures. The spreadsheet determines the soil classification from measured CPT quantities using the procedure of Robertson (1990). The spreadsheet modifies the values of penetration resistance to reflect the effects of aging since the time of the historic earthquake. (Since the Simplified Procedure was developed primarily from case histories of penetration resistance conducted AFTER earthquake/liquefaction events, a correction for densification due to liquefaction is not applicable with this methodology.) The spreadsheet then calculates a factor of safety against liquefaction at each depth using the Simplified Procedure and the relationships between SSR and CPT tip resistance developed by Stark and Olson (1995). If necessary, another trial value of a_{max} is used until the calculated factor of safety at a known depth of marginal liquefaction is approximately equal to unity. The spreadsheet can also be used with CPT soundings and a design value of a_{max} to evaluate liquefaction potential at a given site.

The remaining months of this study will focus on using site response analyses and attenuation relationships with the calculated values of a_{max} and magnitude to make a determination of the maximum bedrock (instead of near ground surface) acceleration and magnitude of the New Madrid earthquakes of 1811 – 1812. A possible energy based procedure for evaluating liquefaction susceptibility will also be studied.

<u>References</u>

Ishihara, K., Kokusho, T., and Silver, M. L. (1989). Recent Developments in Evaluating Liquefaction Characteristics of Local Soils. State-of-the-Art Report Proc. 12th International Conference on Soil Mechanics and Foundation Engineering Rio de Janeiro, Brazil, Vol. 4, pp. 2719-2734.

Mesri, G., Feng, T. W., and Benak, J. M. (1990). Postdensification Penetration Resistance of Clean Sands. Journal of Geotechnical Engineering, Vol. 116, No. 7, pp. 1095-1115.

Robertson, P. K. (1990). Soil Classification Using the Cone Penetration Test. Canadian Geotechnical Journal, Vol. 27, No. 1, pp. 151-158.

Stark, T. D. and Olson, S. M. (1995). Liquefaction Resistance Using CPT and Field Case Histories. Journal of Geotechnical Engineering, Vol. 121, No. 12, pp. 856-869.

Interpretation of Ground Shaking from Paleoliquefaction Features

Grant Award 01HQGR0030

Dr. Timothy D. Stark Stark Consultants, Inc. 401 W. Indiana Ave. Urbana, IL 61801
Telephone: (217) 840-8263 stark@shout.net
Additional Investigators: Dr. S. F. Obermeier, E. J. Newman, and J. M Stark

NEHRP Element: II (Memphis Metropolitan Area)
Keywords: Paleoliquefaction, Strong Ground Motion, Earthquake Scenarios

SUMMARY OF PROJECT FROM 12/15/00 to 10/14/01

Tasks Completed

1. Located sites of marginal liquefaction features along Wolf River, east of Memphis, TN
2. Obtained and interpreted data from seven cone penetrometer tests (CPT) conducted by Georgia Tech at site.
3. Obtained and interpreted data at marginal liquefaction sites inaccessible by CPT rig using portable dynamic cone penetrometer (DCP).
4. Performed DCP testing at sites of previous CPT tests to develop correlation between DCP penetration resistance and standard CPT penetration resistance
5. Developed correlations relating DCP resistance to CPT resistance
6. Collected soil samples during DCP testing at sites of marginal liquefaction for analysis.
7. Developed grain-size distributions for soils at sites of marginal liquefaction.
8. Developed methodology for estimating increase in CPT resistance since1811 – 1812 due to soil aging.
9. Developed methodology for estimating increase in penetration resistance, i.e. N value, due to liquefaction.
10. Developed methodology for estimating decrease in void ratio due to liquefaction and verified by relating to increase in penetration resistance, N value, caused by liquefaction.
11. Located depth of water table at the Wolf River test site at the time of the 1811 – 1812 earthquakes.
12. Developed spreadsheet with the following features:
    a. Continuous CPT sounding data can be directly imported.
    b. Soil is classified based on quantities measured during CPT testing.
    c. Corrections for soil aging are applied.
    d. Factor of safety against liquefaction is calculated using the Simplified Procedure.

Interpretation of Ground Shaking from Paleoliquefaction Features

Grant Award 01HQGR0030

Dr. Timothy D. Stark Stark Consultants, Inc. 401 W. Indiana Ave. Urbana, IL 61801
Telephone: (217) 840-8263 stark@shout.net
Additional Investigators: Dr. S. F. Obermeier, E. J. Newman, and J. M Stark

NEHRP Element: II (Memphis Metropolitan Area)
Keywords: Paleoliquefaction, Strong Ground Motion, Earthquake Scenarios

FUNDING EXPENDED TO DATE

Budget Item	Total Proposed Funding	Funding Expended through 9/15/01	Funding Remaining
Personnel:			
Dr. Timothy D. Stark	12,480.00	3,260.00	9,220.00
Field Engineer	15,600.00	15,600.00	0.00
Independent Reviewer	1,000.00	0.00	1,000.00
Research Engineer	15,600.00	2,730.00	12,870.00
Direct Costs:			
Sampling and Testing	1,000.00	902.70	97.30
Travel Expenses	4,000.00	3,346.27	653.73
Photo/Slide/Copying	240.00	37.00	203.00
Publication Costs	900.00	0.00	900.00
Radiocarbon Dating	1,050.00	0.00	1,050.00
Telephone/Postage	130.00	41.00	89.00
TOTAL	52,000.00	25,916.97	26,083.03